Holo-Resonant Geometry (HRG 2.0): A Holographic Scalar Gauge Model in AdS_5

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Abstract

We reformulate the Holo-Resonant Geometry (HRG) framework on rigorous physical grounds using the Abelian-Higgs model in a fixed AdS_5 spacetime. This formulation provides a tractable, mathematically well-defined model capable of describing scalar condensation, symmetry breaking, and emergent dynamics in a 4D holographic dual. The model replaces previous symbolic structures with testable field dynamics and lays a foundation for future interpretations of anomalous energy deposition and mass generation via bulk-boundary correspondence.

1 Model Setup and Field Content

We consider a fixed AdS_5 background with coordinates $x^M = (x^\mu, z)$, where z is the radial (bulk) coordinate and x^μ are the usual 4D spacetime coordinates.

Fields:

- $\phi(x^M) \in \mathbb{C}$: Complex scalar field (condensate field)
- $A_M(x^M)$: 5D U(1) gauge field

Background metric:

$$ds^2 = \frac{L^2}{z^2}\left(-dt^2 + d\vec{x}^2 + dz^2\right)$$

2 Lagrangian and Equations of Motion

Bulk Lagrangian:

$$\mathcal{L} = -\frac{1}{2}|D_M\phi|^2 - V(|\phi|) - \frac{1}{4}F_{MN}F^{MN},$$

with:

- $D_M = \partial_M - ieA_M$, the U(1)-covariant derivative
- $F_{MN} = \partial_M A_N - \partial_N A_M$, the field strength
- $V(|\phi|) = m^2|\phi|^2 + \lambda|\phi|^4$, a Higgs-type potential

Equations of motion:

$$\begin{aligned} &D^M D_M\phi - \frac{\partial V}{\partial\bar{\phi}} = 0, \\ &\nabla^M F_{MN} = j_N = ie(\bar{\phi}D_N\phi - \phi D_N\bar{\phi}) \end{aligned} \tag{1}$$

3 Holographic Dictionary and Boundary Operators

Field/operator correspondence:

- $\phi \leftrightarrow \mathcal{O}_\phi$: scalar operator with conformal dimension Δ
- $A_\mu \leftrightarrow J^\mu$: conserved U(1) current

Projection rule:

$$\langle\mathcal{O}_\phi(x^\mu)\rangle = \lim_{z\to 0} z^{-\Delta}\phi(x^\mu, z)$$

The dimension Δ satisfies:

$$\Delta(\Delta - 4) = m^2L^2$$

4 Symmetry Breaking and Condensate Formation

For $m^2 < 0$, the potential allows a nonzero vacuum expectation value (VEV) for ϕ, leading to:

$$\langle\mathcal{O}_\phi\rangle \neq 0$$

This spontaneous symmetry breaking induces nontrivial dynamics on the boundary, associated with superconducting/superfluid-like phases.

5 Towards Spectrum and Observables

To compute particle-like excitations:

- Linearize around background solution: $\phi = \phi_0(z) + \delta\phi(x^\mu, z)$
- Fourier transform in 4D: $\delta\phi \sim e^{-i\omega t + i\vec{k}\cdot\vec{x}}f(z)$
- Solve resulting eigenvalue problem: spectrum of $\omega(k)$

These spectra correspond to masses of 4D boundary excitations.

6 Parameter Selection and Boundary Conditions

6.1 Mass parameter m^2

We choose a value close to the Breitenlohner-Freedman (BF) bound to ensure stability yet allow condensation. A standard choice is:

$$m^2 L^2 = -3 \quad \Rightarrow \quad \Delta = 3$$

6.2 Quartic coupling λ

We assume $\lambda = 0$ initially for simplicity, treating the potential as effectively quadratic, sufficient to allow condensation and simplify numerics.

6.3 Charge e

We set $e = 1$ as a normalization choice.

6.4 Boundary Conditions

We impose the following asymptotic behavior near $z \to 0$:

- For the scalar field:

$$\phi(x^\mu, z) \sim z^{\Delta}(\phi^{(0)}(x^\mu) + \dots) + z^{4-\Delta}\langle \mathcal{O}_\phi(x^\mu)\rangle + \dots$$

  We fix the source term $\phi^{(0)} = 0$ to induce *spontaneous* symmetry breaking.

- For the gauge field:

$$A_t(x^\mu, z) \sim \mu - \rho z^2 + \dots$$

  where μ is the boundary chemical potential and ρ the charge density.

7 Relation to EVP

HRG 2.0 should not be seen as a direct extension of the Etheric Vortex Paradigm (EVP). Instead, it is a scientific restart inspired by similar aspirations but realized with tools from AdS/CFT and gauge theory.

- **Inspired Goals, Not Direct Descent:** HRG 2.0 addresses the gap left by EVP's lack of rigorous dynamics.
- **Symbolism as Emergent, Not Fundamental:** Where EVP embedded symbolic constructs, HRG 2.0 allows only for the emergence of patterns in spectral data. The symbolic layer is interpretative, not causative.
- **Clarified Position:** HRG 2.0 supersedes EVP as a viable model of physical unification. EVP remains a philosophical precursor.

A Notation and Parameters

- L: AdS radius
- m^2: scalar mass squared; must obey Breitenlohner-Freedman bound $m^2 L^2 \geq -4$
- λ: quartic coupling (usually ≥ 0)
- e: U(1) charge of ϕ

B EVP vs. HRG 2.0 Comparison

Table 1: Comparison of EVP (Original) vs. HRG 2.0.

Feature	**EVP (Original)**	**HRG 2.0 (This Paper)**
Dimensionality	3+1 spacetime	4+1 AdS (holographic)
Scalar field	Real scalar, vortex	Complex scalar, condensate
Gauge field	Absent	5D U(1) field A_M
Gravity	Emergent (heuristic)	Background metric (AdS)
Symbolism	Foundational	Emergent-only
Mass mechanism	Vortex-coded formula	Holographic condensate
Dynamics	Postulated	Lagrangian-based
Experimental	Speculative anomalies	Boundary observables